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# Large inter annual variation in air quality during the annual festival 'Diwali' in an Indian megacity

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ABSTRACT

A network of air quality and weather monitoring stations was established under the System of Air Quality Forecasting and Research (SAFAR) project in Delhi. We report observations of ozone ($O_3$), nitrogen oxides ($NO_x$), carbon monoxide (CO) and particulate matter ($PM_{2.5}$ and $PM_{10}$) before, during and after the Diwali in two consecutive years, *i.e.*, November 2010 and October 2011. The Diwali days are characterised by large firework displays throughout India. The observations show that the background concentrations of particulate matter are between 5 and 10 times the permissible limits in Europe and the United States. During the Diwali-2010, the highest observed $PM_{10}$ and $PM_{2.5}$ mass concentration is as high as 2070 μg/m3 and 1620 $\mu g/m^3$, respectively (24 hr mean), which was about 20 and 27 times to National Ambient Air Quality Standards (NAAQS). For Diwali-2011, the increase in $PM_{10}$ and $PM_{2.5}$ mass concentrations was much less with their peaks of 600 and of 390 $\mu g/m^3$ respectively, as compared to the background concentrations. Contrary to previous reports, firework display was not found to strongly influence the $NO_x$, and $O_3$ mixing ratios, with the increase within the observed variability in the background. CO mixing ratios showed an increase. We show that the large difference in 2010 and 2011 pollutant concentrations is controlled by weather parameters.



## Introduction

The World Health Organization (WHO) and the World Bank have reported in Indian megacity, Delhi, as the second most polluted megacity in the world with respect to particulate pollution (World Bank, 2004). The high levels of pollutants are mainly due to its large population and economical growth. Delhi and its National Capital Region (NCR) are India's largest and the world's second largest agglomeration with a population of about 22.2 million in 2011. The city of Delhi itself is the seventh most populated metropolis in the world. Delhi has a population density of 11,297 $km^{-2}$ and a decadal population growth rate of 20.96%, one of the highest in the world (Census of India, 2011). This rapid urbanization and related industrialization have caused an increase in the number of vehicles, industrial units and power plants in the Delhi and NCR over the last two decades. More than 400,000–450,000 private and commercial vehicles are annually added to Delhi and NCR, which had more than 1.74 million total vehicles in 2011 (www.delhi.gov.in).

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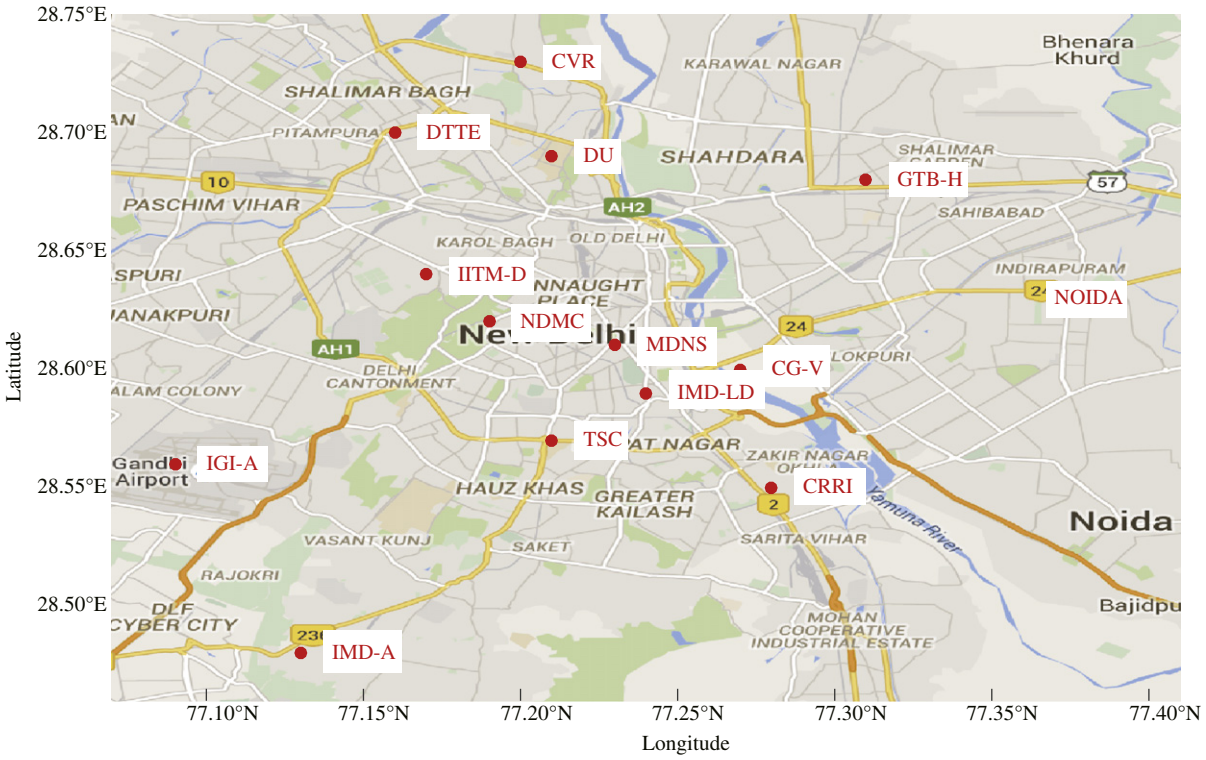


**Fig. 1 – Network of air quality monitoring stations and automatic weather stations established in Delhi as a part of the System of Air Quality Forecasting and Research (SAFAR) programme used for the Diwali period in 2010 and 2011. Map images from Google Earth. CG-V: Commonwealth Games Village; CRRI: Central Road Research Institute; CVR: Sir C. V. Raman Industrial Training Institute, Dheerpur; DTTE: Directorate of Training and Technical Education, Pitampura; DU: Delhi University; GTB-H: Guru Tteg Bahadur Hospital; IGI-A: Indira Gandhi International Airport; IITM-D: Indian Institute of Tropical Meteorology, Delhi; IMD-A: Indian Meteorological Department — Ayanagar; IMD-LD: Indian Meteoroogical Department — Lodhi Road; MDNS: Major Dhyanchand National Stadium; NMDC: National Mineral Development Corporation; NOIDA: National Centre for Medium Range Weather Forecasting, Noida; TSC: Tyagaraj Sports Complex.**

Diwali is an Indian festival celebrated in October or November every year with huge firework displays across the India over 5 days, with the main event falling on the third day. In the past, several studies have reported an increase in trace gas and particle pollutions during the Diwali period in Delhi, Lucknow, Hisar and Howrah (Barman et al., 2009; CPCB, 2010; Ganguly, 2009; Perrino et al., 2011; Ravindra et al., 2003; Thakur et al., 2010; Kulshrestha et al., 2004; Singh et al., 2010). Jiang et al. (2014) also observed that significant and short-term impacts on fine particles ($PM_{2.5}$) due to firework display on the days of Lunar New Year, Lunar Fifth Day, and Lantern Festival in 2013. However, all studies in the literature are limited by a coarse geographical or temporal resolution.

Fireworks used during the festival typically consist of paper tubes filled with organic, non-metallic and metallic elements (charcoal, sulphur, silicon, boron, aluminium, magnesium titanium), oxidizing agents (nitrate, chlorates), reducing agents (sulphur, charcoal), colouring agents (strontium or lithium, copper, barium, sodium, iron or charcoal) and a binder (dextrin) (Schwartz et al., 1996; Drewnick et al., 2006; Vecchi et al., 2008). Large scale fireworks cause emission of various pollutants including sulphur and charcoal compounds, trace gases, traces metals and particulate matter (Ravindra et al., 2003; Kulshrestha et al., 2004; Wang et al., 2007; Perrino et al., 2011).

In this study, we report the observations of trace gases and particulate matter in the Delhi and NCR during the Diwali festival in 2010 and 2011. This work expands on the previous studies by reporting the first high geographical resolution observations using a large air quality monitoring network within Delhi and NCR enabling increased understanding on the distribution of the pollutants resulting from firework displays.

## 1. Site Description and Measurements

Delhi and NCR are situated, on an average, at a height of 216 m above mean sea level and covers ~1483 $km^2$ of industrial area including the suburban towns of Gurgaon, Faridabad, Noida and Ghaziabad. The System of Air quality Forecasting and Research (SAFAR) programme, a network of air quality monitoring stations (AQMSs) and automatic weather station (AWS), was setup in and around the NCR (http://safar.tropmet.res.in/) in 2010. This project was initiated